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CHEMICAL CHANGES IN STORED GRAINS

A Selected and Annotated Bibliography

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FOREWORD

The Ever Normal Granary program presupposes the accumulation of larger-than-normal quantities of grain and its storage for longer-than-usual periods of time. This program was adopted by the U. S. Department of Agriculture in 1938, and recently was subscribed to by the three other major wheat-exporting countries and by Great Britain under the terms of the World Wheat Agreement of June 27, 1942.

The possibility for grain to accumulate under an Ever Normal Granary program is evidenced by the size of crop carry-overs in the United States in recent years in comparison with those of former years. In the case of wheat the July 1 carry-over increased from an average of 238 million bushels during the 10-year period, 1929-38, to 282 million bushels in 1940, 385 million bushels in 1941, 632 million bushels in 1942, and to an estimated July 1, 1943 carry-over of 700 million bushels. A similar tendency is shown for corn. From an average of 212 million bushels for the 10-year period 1929-38 the October 1 carry-over rose to 583 million bushels in 1939, 695 million bushels in 1940, 646 million bushels in 1941, and 492 million bushels in 1942.

Evidence that under the Ever Normal Granary program some grain is now stored longer than one crop season, the former usual limit, may be had from the Commodity Credit Corporation report of July 1942. This report shows that the Corporation had in storage approximately 200 million bushels of 1941 crop wheat and 100 million bushels of 1940 or some previous crop wheat. Until recently, a similar situation existed with regard to corn.

Because of the existence of these large accumulations and because of the war situation necessitating the maintenance of adequate stocks of grain to meet full domestic, lend-lease, and post-war foreign relief requirements, the possible effect of length of storage on the physical and chemical properties of grain becomes an important question. A full knowledge of the character and extent of these changes is necessary for the proper utilization of such grain.

The Official U. S. Grain Standards have been developed to cover adequately the changes in the physical aspects of the grain resulting from storage. But up to the present time not much attention has been given to chemical changes not reflected in the physical appearance of the kernels. These chemical changes, however, may be of utmost importance in the use of the grain both on the farm and in industry. To make available the sources of information pertaining to this particular aspect of storage, the following selected and annotated bibliography has been prepared.

The sources consulted in preparing this bibliography were limited to those available at the Northern Regional Research Laboratory.

SUMMARY

The literature concerning the effect of storage on the chemical composition of grain is marked by the dearth of specific results. Up to very recent years the greatest amount of work seems to have been reported on the products of grain, principally flour, rather than on the grain itself.

On the basis of available information it appears that temperature and moisture are the fundamental factors concerned with the deterioration of stored grain and the products therefrom. Type of container or type of storage, insect infestation, stage of maturity of the grain and its condition when stored are contributing or secondary factors.

It appears that, in general, wheat with 13 percent or less moisture will not be damaged by heating in storage, while wheat with more moisture is likely to be damaged. (See item No. 52). The line between safe and unsafe storage is not a sharp one and will vary with temperature, humidity of the air, and other factors. In this connection it has been found that wheat with high moisture content may be stored at 41° F., or lower temperatures, for many months without suffering damage to its milling and baking qualities. (See item No. 82). However, under normal temperature conditions it appears that the baking quality of wheat suffers on prolonged storage; in some cases showing very marked deterioration.

In the case of all grains or beans it has been found that viability is maintained for long periods when the commodity is stored with low moisture content at either low or relatively high temperatures.

The available information on the actual chemical changes in stored grain is not sufficient to support general conclusions. Specific experiments have indicated that the vitamin A content of stored corn decreases by as much as 50 percent after 3 or 4 years. (See item No. 88). Another series of experiments showed notable decreases in the percentage of sugar in stored corn, while for barley and oats small decreases in sugar content were shown, and for wheat a slight increase was noted. (See item No. 42).

Experiments on the chemical changes in stored flour indicate that gluten quality is affected by the presence of unsaturated fatty acids which have a tendency to increase when the flour is stored under unfavorable conditions. (See item Nos. 4, 35, 37, 43, 70, 73). The observed alterations occurring in the proteins from storage of wheat, corn, soybeans and flour are a decrease in solubility, a partial breakdown of the proteins as indicated by the amount of nitrogen precipitable by trichloracetic acid and by an increase in amino nitrogen, and decrease in digestibility. (See item Nos. 31, 32, 33, 34).

The changes occurring in the carbohydrate and oil constituents as the result of storage have been discussed only with coincident changes in gluten.

CHEMICAL CHANGES IN STORED GRAINS

A Selected and Annotated Bibliography

1. Aamodt, O. S., and McCalla, A. G. Quality and keeping properties of flour from wheat grown on the black and gray soils of Alberta. Can. Jour. Research. Sec. C. Vol. 13. September 1935.

"Weight per bushel and milling yields of hard red spring wheats grown on the black soil at Edmonton were the same as for the same varieties grown on the gray soil at Fallis. Grade, protein content, and baking quality of Edmonton grown samples were superior. The flour from most of the Edmonton grown samples retained its quality for at least two years after milling, but flour from most of the Fallis grown samples had deteriorated so much during 10 months' storage that it was unfit for breadmaking. Flour from Reward showed less deterioration than that from any other standard variety grown at Fallis. It also had the best original baking quality, and is the only one of the recommended varieties considered satisfactory for the gray soil area."

2. Anderson, J. Ansel. Effect of insecticides on wheat quality. pp. 29-30, Fifteenth Annual Report, Board of Grain Commissioners, Grain Research Laboratory, Winnipeg, Manitoba. 1942.

"Larvacide, Larvacide mixed with carbon-tetrachloride, Weevil-cide, Weevil-Insecticide and Westofume all taint wheat, but the taints produced do not persist on subsequent aeration. It is believed that the amount of aeration produced by the normal handling of fumigated grain will be sufficient to reduce any taint to a level which is barely perceptible, even if twice the normal dosage of any of the fumigants is applied. Five times the normal dosage does not have any apparent injurious effect on either wheat strength or baking quality."

3. Back, E. A., Cotton, R. T., and Ellington, G. W. Ethylene oxide as a fumigant for food and other commodities. Jour. Econ. Entomology. Vol. 23, No. 1, pp. 226-231. February 1930.

"In ethylene oxide, when used as directed, we have a fumigant which, in addition to possessing freedom from the fire and explosion hazard and extreme toxicity to man, does not appear to leave in or upon the treated materials obnoxious odors, or residues harmful to man or animals. It is believed that many commodities will be fumigated more successfully and with less danger when the details of application, particularly with carbon dioxide, have been worked out."

4. Barton-Wright, E. C. Studies on the storage of wheaten flour: III. Changes in the flora and the fats and the influence of these changes on gluten character. Cer. Chem. Vol. 15, No. 4, pp. 521-541. July 1938.

"An investigation has been made of the changes that take place in the bacterial and fungal flora of flour kept under storage conditions. It was found that the bacterial numbers always diminish with increasing time...

"Deterioration of gluten quality during storage of flour, especially low-grade flours, was found to depend on the unsaturated fatty acids present in the oil fraction. In flours with a moisture content of 16 percent and over, the oil content fell rapidly during storage and this was found to coincide with increase in fungal numbers and was not accompanied by deterioration in gluten quality.

"In low-grade flours of normal moisture content (14 to 15 percent) or less with a high oil content it was found that after 6 to 8 weeks' storage the gluten tended to break up on washing, whereas in the moist samples the gluten improved in quality. This improvement in the quality of the gluten was found to be due to (1) the removal of fats and fatty acids by fungi and (2) some improving action due to the fungi themselves.

"The effect of different saturated and unsaturated fatty acids on gluten is described and discussed. Saturated acids of high molecular weight produce only slight shortening effect in gluten. Unsaturated acids produce serious damage in gluten. This damage is due to the presence of double bonds in the acid since when these are removed, e.g., by bromination, the damaging effects are removed.

"Free carboxyl groups are also an essential factor in gluten damage since this is not caused by esters (e.g. fats themselves) or by salts of unsaturated fatty acids.

"Gluten damage by unsaturated acids is not due to pH changes as the effect of, e.g., oleic acid on dough pH is very small (0.1)."

5. Besley, H. J., and Baston, G. H. Acidity as a factor in determining the degree of soundness in corn. U. S. Dept. Agr. Bul. No. 102. 1914.

"The degree of acidity of corn should not necessarily be considered a measure of the percentage of individual kernels that are visibly damaged. It is the soundness and quality of the corn which is indicated by the acidity test, and the results of this investigation suggest the acidity test as a method to be used in determining accurately the soundness and quality of corn."

A number of tables are presented indicating relationships between acidity and germination, temperature, destination of corn, etc.

6. Bracken, A. F., and Bailey, C. H. Effect of delayed harvesting on quality of wheat. Cer. Chem. Vol. 5, No. 2, pp. 128-145. March 1928.

"The baking studies gave proof that wheat which had remained unharvested in the field for 50 days after ripe, subjected to alternate wetting and drying, showed no indication of deterioration as determined by loaf volume and loaf texture.

"Thus it may be stated as a result of these tests that dark hard wheat of the Turkey Red type does not deteriorate in quality upon standing uncut in the field when subjected to alternate wetting and drying, in spite of the fact that the grains bleach and lose weight per measured volume."

7. Briggs, Charles H. What do baking tests disclose? Northwestern Miller. Vol. 6, No. 8, p. 745. August 28, 1929.

"The amount of gluten which the flour contains is often correlated more nearly with the water absorption than is the moisture content. Again, the water absorption is often inversely proportional to the amount of soluble carbohydrates (sugars, etc.) present, which may be taken as a crude measure of the amount of enzymic action which has taken place, and particularly, though indirectly, of the proteolytic action that has occurred before the dough is made and that will occur during fermentation."

8. Cathcart, William H., and Killen, Edward J. Changes in flour on storage with special reference to the effect of different types of bags. Cer. Chem. Vol. 16, No. 6, pp. 798-817. 1939.

"Two different samples of chemically bleached and matured flour were stored separately in four different types of bags, namely ordinary cotton, paper-lined, jute, and grain. They were stored under average commercial bake-shop conditions. The samples were analyzed at regular intervals for moisture, ash, protein, and absorption, and baking tests were made. The kind of bag had little effect on the analyses of the baking quality of the flour. In all cases absorption increased during storage, ash and protein showed no change, and the baking quality in one sample fell off after the fourth month and in the other after the sixth month. Deterioration in the latter case was due to infestation."

9. Coleman, D. A. Unsoundness in wheat. Grain Inspectors' Letter. June 13, 1931.

"The spoilage of wheat is the direct result of harvesting and storing of wheat with an excess of moisture. It makes but little difference whether the wheat is cut and stacked in a wet condition, or whether the wheat is threshed and stored with excess moisture,

the ultimate results are the same. Stimulated by the high moisture content in the grain, rapid respiration or fermentation takes place, heat develops, with the result that the grain spoils, the extent of the spoilage depending upon how long the wheat has been exposed to the fermentation process and how much heat of fermentation has developed."

10. Coleman, D. A., and Rothgeb, B. E. Heat-damaged wheat. U. S. Dept. Agr. Tech. Bul. No. 6. 1927.

Tables showing the chemical composition of heat-damaged wheat are given along with data on baking results.

11. Coleman, D. A., Rothgeb, B. E., and Fellows, H. C. Respiration of sorghum grains. U. S. Dept. Agr. Tech. Bul. No. 100. 1928.

"Storage tests made under laboratory conditions bear out in a general way the findings of the respiration studies; namely that if the temperature is sufficiently high (100° F. or more) sorghum grains that contain over 14 percent of moisture will go out of condition."

12. Cox, J. H. The drying for milling purposes of damp and garlicky wheat. U. S. Dept. Agr. Bul. No. 455. 1916.

"The results of these investigations show practically no bad effects from the drying of wheat at 140° F. and indicate that this temperature is probably the most satisfactory for the drying of wheat, either with or without garlic, for milling purposes."

13. Culbertson, C. C. Debunk fear of old corn. Wallaces' Farmer and Iowa Homestead. Vol. 67, No. 14, p. 11. July 11, 1942.

C. C. Culbertson, of the Iowa Agricultural Experiment Station, stated that throughout Iowa during the year there had been cases of edema etc., apparently caused by feeding vitamin-poor old corn, but that in most of the edema cases the steers had been getting both old hay and old corn. If good legume hay is fed along with old corn, there should be no such trouble. In this year's experiment results showed that there was less difference than was at first indicated in the feeding of old corn compared to new, both with the corn fed shelled and in combination with alfalfa hay. As a matter of fact, it was found that some 1937 corn did a little better than the 1940 corn because the latter--although three years younger--had dried to a harder condition.

14. Duvel, J. W. T. The deterioration of corn in storage. U. S. Dept. Agr. Cir. No. 43. 1909.

15. Fenton, F. C., and Swanson, C. O. Studies on the qualities of combined wheats as affected by type of bin, moisture and temperature conditions. Cer. Chem. Vol. 7, pp. 428-448. 1930.

p. 439 - Table shows germination, and composition as affected by different conditions of storage--(no general conclusions).

16. Fifield, C. C., and Bailey, C. H. The march of acidity in stored flours. Cer. Chem. Vol. 6, No. 6, pp. 530-40. November 1929.

"It has been generally observed that the acidity of flour increases progressively with the lapse of time.....The rate of change in acidity has appeared to be a function of flour grade, moisture content, humidity of the atmosphere, temperature, and possibly other factors."

17. Fisher, E. A., Halton, P., and Carter, R. H. Studies on the storage of wheaten flour: I. The influence of storage on the chemical composition and baking quality of flour. Cer. Chem. Vol. 14, No. 2, pp. 135-161. March 1937.

"It is well known that wheat flours improve in baking quality during storage. This improvement continues for some time until it reaches a maximum, after which progressive deterioration sets in, the flour becoming eventually unfit for breadmaking. Flours, even when made from good sound wheat, vary widely in their response to storage.....After the first deterioration has proceeded for some time a second improvement sets in, which in turn may be followed by a second deterioration. A similar periodicity occurs in changes observable in many of the chemical properties, among which may be mentioned hydrogen-ion concentration, buffer value, total acidity, soluble nitrogen and, above all, in amount and quality of the washed out gluten. These changes are much more marked and take place more rapidly the higher the moisture contents of the flours, and also show very marked differences according to the nature and grade of the flour.....Flour which has become useless for breadmaking by prolonged storage, or by less prolonged storage under unsatisfactory conditions, has a marked improving action when added at the rate of 2 percent to otherwise untreated flour. The improvements resulting are improved dough body and stability, improved oven spring, and improved colour, softness and spring of crumb, and are quite comparable with those brought about by heat treatment processes, or by the use of over-heat-treated flours."

18. Franke, Erich--head of the production laboratory of the Fleischmann Yeast Company at Pekin, Illinois. Observations, based on 15 years' experience in fermentation industries in Czechoslovakia and this country, on characteristics of stored grains.

Rye and corn begin to show a resistance to malt saccharification some 8 or 9 months after harvesting. This resistance remains

essentially the same from then on. Treatment with malt diastase for a longer time will increase the saccharification to the original value. Addition of more enzyme will help to a certain extent, but will not bring saccharification to the original rate. These observations have been repeated year after year and it is evident that they are not due to seasonable variations. Experiments have shown that neither the moisture nor the nitrogen content of the grains changes. Change in strength of the malt diastase was investigated but showed no difference, indicating the difference to be in the grain itself.

It was further noted that during saccharification, starch from fresh grain stained first blue, then violet, then red, and finally was colorless with iodine, while the old grain went from blue to colorless without going through the other colors.

In connection with the storage of potatoes for use by distilleries in the production of alcohol, it was found that the piping of carbon dioxide from the distillery to the storage bins prolonged the satisfactory storage period of the potatoes. This obviously slows down respiration and delays enzymic changes.

19. Geddes, W. F. Discussion before a meeting of the Minneapolis chapter, Society of Grain Elevator Supt's. - Minneapolis, October 27, 1942. Feedstuffs, Vol. 14, No. 45, p. 14. November 7, 1942.

....."Regardless of the effects of various mold growths on grain heating, the grain respiration process is a common cause of damage. By studies of the carbon dioxide produced, curves have been drawn to indicate safe moisture limits for various types of grain in storage when other things are equal. The 'break' in the curve, that is, the danger point, is reached more rapidly for some grains than others, the oil content being a major factor in this. Flax, for example, has the earliest break, rye the latest. Corn curves indicated that at 11 percent moisture virtually no carbon dioxide (or respiratory heat) was produced. At 12 percent a small amount is evolved, and at 14 percent a much larger amount was obtained over a given period. The break occurs there--above 14 percent heating mounts rapidly. Cereal grains were fairly well grouped, corn being slightly quicker to heat than others. The tests were conducted at a relatively high initial temperature."

Dr. Geddes explained that since oil was not miscible, the moisture content of non-oil portions of grains was higher than would be indicated by grain weight, thus accounting for the more rapid heating of grains higher in oil.

Work on soybeans was begun only last year. Because of its oil content, its heating curve falls between corn and flaxseed.

20. Grain and Feed Journals. Wheat treated with ethylene keeps better. Grain and Feed Jour., Vol. 88, No. 6, p. 267. March 25, 1942.

"Bin-burning of wheat having a high moisture content can be retarded by the use of ethylene gas in the storage bins, research workers of the U. S. Department of Agriculture and the Department of Milling Industry at Kansas State College have found. The gas, at a concentration of approximately one part in 10 thousand of air in the bin was blown into the bin while the damp wheat was being stored."...

The treatment will reduce the rate of heating and will permit the farmer or grain handler to store high-moisture wheat for approximately two weeks, until it can be dried down to a safe moisture content.

"Wheat that was allowed to mature fully in the field before harvesting was also included in the ethylene storage research project. The investigators found that the gas apparently hastened the ageing process through which wheat must go after harvesting before it will make flour of satisfactory baking quality."

21. Grain and Feed Journals. Sick wheat. Vol. 89, No. 1, p. 11. July 8, 1942.

"Sick wheat is but a new name for an old condition resulting from storage when damp. Prior to the advent of the combine when wheat was cut with the binder and stored in barns or stacks before threshing, sick wheat was usually referred to as mow-burned, stack-burned, header damaged. Each condition was usually accompanied by a musty or sour odor and such wheat was considered unfit for milling purposes. Briefly stated, the combine plus wet grain, plus storage, leads to heating, mustiness and enzymic action--result sick wheat."

22. Grain & Feed Journals. Watch out for sick wheat. Grain & Feed Jour. Vol. 89, No. 3, p. 109. August 12, 1942.

"High moisture, and failure to turn wheat sufficiently during the early weeks of storage are the immediate causes of sick wheat. O. F. Phillips, Chairman of the Board of Review at Chicago, top grain supervision office of the U. S. Dept. Agr. says: 'Sick wheat is suffocated wheat. The germ of the wheat berry is a living organism. It breathes. When suffocated for lack of air, intermolecular respiration takes place. This breaks down the starch cells and the wheat starts to deteriorate. The germ turns color. It becomes gray, or reddish brown, or black. The bran coat is soon affected and the berry takes on a dead, lifeless, sometimes skin burned appearance. If sick wheat is left to natural processes it becomes heat damaged. Eventually the whole berry

will become black and charred.'"

"Sick wheat is not a new condition that has suddenly dropped upon us. It is merely another term for an old condition. Other terms used for the same thing in farm parlance are 'bin-burned', 'mow-burned', 'header damaged', and 'stack-burned'. Truth is that wheat so damaged was left to look after itself when it was too wet to do so. The result is sick wheat. That was how the federal department of agriculture officials looked at it back in 1925 when the term 'sick' originated."

23. Grain Inspectors' Letter. Issued from General Field Headquarters, Grain Division, Bureau of Agricultural Economics. October 1938.

"During harvest time there was considerable rainfall in a part of the winter wheat belt. It appears, as a result of this condition, that quite a volume of wheat with relatively high moisture content went into farm storage. As a result, there has been more or less development of storage damage or 'sick wheat', some of which is now arriving at the various terminal markets."....

24. Greaves, J. E. Changes in flour during storage. Farm and Home Science, Vol. 3, No. 2, Utah Agr. Exp. Sta. June 1942.

....."In this experiment 13 fifty-pound sacks of flour were stored for three years."

....."The water-soluble phosphorus content of the flour increased and the alcohol soluble phosphorus content decreased as the flour aged. Therefore, it is evident that during storage there was a slow breaking down of the complex phosphorus-carrying proteins and of the fat-carrying phosphorus. Inasmuch as yeast requires large quantities of phosphorus in its metabolism, it is probable that this is one of the benefits resulting from the ageing of flour.

"During the early period of storage autolytic changes resulting in protein cleavage may have been rapid enough to neutralize not only the acid produced but to have combined with some at first present. Later protein cleavage may have decreased relative to acid production with the resulting measurable increase in acidity, or what is more probable, the acids in the flour were used up in the normal metabolism of the cell enzymes. This latter supposition implies that the decrease in acidity is owing to the enzymic action which plays a part in the normal ripening of the wheat. Therefore, what we have is the normal ripening process, and it does not seem unreasonable to assume that this enzymic process may occur during the storage period of flour. Possibly the ripening process is complete at the point of neutrality and the increase in acidity comes from decomposition. This may closely correlate with other beneficial changes occurring in flour, and if sufficiently studied may give an

exact criterion for measuring changes in storages of not only grains and grain products but also fruits and vegetables.

"In most of the flours the water-soluble carbohydrates increased owing to storage. Some flours remained unchanged and a few decreased in water-soluble carbohydrates. Two facts stand out from a study of the changes in the carbohydrates as the result of storage: (1) There was a variation in water-soluble reducing sugars occurring in different flours, and (2) there was a tendency for the water-soluble carbohydrates to increase during storage, thus indicating a diastatic action. This increase in soluble sugars results in more available food for the yeast which breaks the carbohydrates down with the production of carbon dioxide, so necessary in the leavening of bread.

"Water-soluble basic nitrogen decreased slightly in most flours as a result of ageing. This may be owing to an actual condensing of protein resulting in a more elastic gluten."

25. Greaves, J. E., and Hirst, C. T. The influence of storage on the composition of flour. Utah Agr. Exp. Sta. Tech. Bul. 194, (1925). C. A. Vol. 20, p. 20316. 1926. *

....."The H-ion concentration in every flour examined first decreased and later increased. As deterioration set in there was increase in the H-ion concentration of the flour. No evidence was obtained by the Sorenson titration method that protein cleavage occurs during storage. From 1.39 to 3.52 percent of the N of these flours occurred as water-soluble basic N. Soluble carbohydrates increased progressively during the storage period."

26. Greaves, J. E. Changes in stored flour. American Miller, Vol. 54, p. 376,(1926). C. A. Vol. 20, p. 20317. 1926. *

"At the Utah Experiment Station there were stored thirteen 50-lb. sacks of flour from December 1921 to January 1925..... The results indicate that it is only inferior flours which greatly increase in acidity during four years' storage. There is a variation in the water-soluble reducing sugars found in different flours, and there is a tendency for the water-soluble carbohydrates to increase during storage. The water absorption power of these flours increased considerably. Some of the flours yielded a loaf of greater volume after storage, whereas others registered a shrinkage. The results as a whole point to the conclusion that the flours improve in breadmaking properties on storage and that this benefit comes from ripening changes brought about by the action of enzymes on the carbohydrates, fats and proteins."

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* C. A. abstract checked with bulletin.

27. Gross, Emanuel. Changes in grain seeds during ten years of storage. Z. Landw. Versuchsw. Vol. 20, p. 471 (1917); Biedermann's Zentr. Vol. 48, pp. 395-400 (1919); C. A. Vol. 14, p. 2666[7]. 1920.

Wheat, rye, barley, and oats were stored in beakers or in sacks in an air-dry unheated room.....Oats and barley increased in weight while wheat and rye had the same weight per hectoliter.....The water content of barley decreased most, then oats, rye, and wheat. Increase in dry weight on storage is explained by the fact that starch is converted to maltose and dextrin, which process utilizes water.

28. Hale, W. S., Schwimmer, Sigmund, and Bayfield, E. G. Studies on treating wheat with ethylene: I. Effect upon high moisture wheat, Manuscript from Enzyme Research Laboratory. U. S. Dept. of Agr., Bur. Agr. Chem. and Eng. 1942.

"As a rule, freshly harvested wheat neither bakes nor germinates well. A period of storage is necessary to bring either of these characteristics to the optimum level. Previously reported experiments /Balls and Hale (1940)_7 have shown that wheat, harvested while somewhat immature, underwent an almost immediate increase in baking test and germination capacity when exposed to air containing traces of ethylene. On the other hand, the flour from immature wheat (before treatment with ethylene) was not improved by subsequent exposure to the gas, although eventually it improved, like other fresh flour, on lengthy storage. Thus it seems the effect of ethylene on the baking test takes place in the whole grain. It is accompanied by a temporary rise in carbon dioxide output (frequently referred to as 'respiration'). Furthermore, the effect is not particularly pronounced on grain already aged in storage."

29. Hoyt, L. F. Further fumigation tests with ethylene dichloride--carbon tetrachloride mixture. Ind. and Eng. Chem. Vol. 20, No. 4, p. 931. September 1928.

"The food products after fumigation show different effects. Those rich in fat absorbed the fumigant appreciably but on exposure to the air gradually gave off the fumigant and became edible in 1 to 8 days."

Results of baking tests on Gold Medal flour showed, "There was no detectable difference in the odor, texture, or general appearance of these loaves, and although a faint odor of fumigant could be detected in the flour before use, the fumigant had had no effect on the quality of the gluten and could not be detected in the finished loaf."

Baking tests on whole-grain graham milled from fumigated grain indicated that "No odor of the fumigant could be detected in the hot loaf when broken open--the most severe test."

30. Johnson, Arnold H., and Green, Jesse. Wheat and flour studies XVIII. A study of the nature of the acid responsible for the increase in acidity which occurs in flours during storage. Cer. Chem. Vol. 8, pp. 134-145. 1931.

"It has been known for a long time that flours increase in their acidity during storage."....

"The H-ion concentration of water extracts of stored flours extracted with ether were the same as those of the extracts of the freshly-milled flours.

"The idea is expressed that ether-extractable acids are alone responsible for the changes in H-ion concentration or in acidity (as measured by any method) which occur in flours during storage under proper conditions.

"The acids removed from flour by extraction with ether must, on the average, have rather long carbon chains as their coefficient of distribution between water and ether was of the order .014 to 1."

31. Jones, D. Breese, Divine, J. P., and Gersdorff, Chas. E. F. The effect of storage of corn on the chemical properties of its protein and on its growth-promoting value. Cer. Chem. Vol. 19, No. 6, pp. 819-830. November 1942.

"The effects of storage of ground corn and of whole shelled corn upon the properties of the proteins and upon nutritive value were determined at various intervals over a storage period of two years. The results show that three different types of alterations in the proteins occur: (1) a decrease in the solubility of the proteins, (2) a partial breakdown of the proteins, indicated by a decrease in true protein content, and (3) a decrease in digestibility.

"The extent of the alterations is influenced by temperature, type of container, duration of storage, and nature of the material stored. Samples stored at 76° F. were affected more than those stored at 30° F., and those in bags more than those in sealed glass jars. Changes in the ground corn were greater than those in the whole shelled corn. The total nitrogen and free ammonia remained unchanged. The extent of denaturation of the proteins was measured by determination of solubility in 3 percent NaCl solution, 70 percent alcohol, and 3 percent sodium salicylate. At the end of two years' storage in a bag at 76° F. the solubility of the ground-corn protein in NaCl solution and in alcohol was

approximately 60 percent less than that of fresh material. The true-protein value and digestibility had decreased 32 percent and 29 percent, respectively. The rates of the decreases were much more rapid during the early storage intervals than later.

"Significant decreases in feeding value were also found. During a 42-day feeding period the average gain in weight of albino rats fed with ground corn which had been stored for 6 months in jars at 76° F. was 63 g. in comparison with 84 g. for rats fed with fresh material, and 56 g. for rats fed with material stored for 12 months. The value remained the same at the end of the second year's storage. In every instance less of the stored material than of the fresh material was consumed by the same number of rats in the same time. For material stored 6 months, the gain in weight per gram consumed was the same as for fresh material. For material stored 12 and 24 months, the gain in weight per gram consumed was less."

32. Jones, D. Breese, and Gersdorff, Chas. E. F. The effect of storage on the protein of wheat, white flour, and whole wheat flour. Cer. Chem. Vol. 18, No. 4, pp. 417-434. July 1941.

"The effect of storage under different conditions upon the proteins of white flour, whole wheat flour, and wheat kernels has been studied at various intervals over a period of two years. The results show that three different types of alterations occur: (1) a decrease in the solubility of the proteins, (2) a partial breakdown of the proteins indicated by decrease in true protein content, by decrease in the amount of nitrogen precipitable by trichloracetic acid, and by increase in amino nitrogen, and (3) decrease in digestibility.

"The extent of the changes depends on temperature, type of containers, duration of storage, and the nature of the material stored. Samples stored at 76° F. were affected more than those stored at 30° F., and those in bags more than those in sealed jars. Changes in white flour were in general greater than in whole wheat flour. Significant changes occurred also in the wheat kernels, although not as great as in the flours. The total nitrogen and free ammonia remained unchanged. The extent of denaturation of the proteins was followed by determination of solubility in 3 percent NaCl, 70 percent alcohol, and 3 percent sodium salicylate. The greatest decrease was found in solubility of the proteins of white flour in NaCl. When stored in a bag at 76° F. for two years the percentage decrease amounted to 61 percent, and 57 percent after similar storage in a sealed glass jar. The alteration of the proteins is ascribed to the effect of enzymes and oxidation."

33. Jones, D. Breese, and Gersdorff, Chas. E. F. Changes that occur in the proteins of soybean meal as a result of storage. Jour. Am. Chem. Soc. Vol. 60, No. 3, pp. 723-724. 1938.

"Studies have been started to investigate the nature and extent of changes which occur in the proteins of seeds (both whole and ground) when stored under different conditions. Results thus far obtained show that marked changes in the chemical properties of the proteins of ground soybeans occur very soon after grinding. Some of these changes suggest a decrease in the biological value of the proteins.

....."By the end of six months the digestibility of the protein of the low-fat meal stored in bags at 76° had dropped nearly 19 percent below that of the meal when freshly ground. The greatest changes occurred at 76°, although at 30° the changes were surprisingly high. Greater changes occurred in the meals stored in bags than in those stored in sealed jars. Of interest is the consistently greater changes that occurred in the low-fat samples than in the high-fat samples. The total nitrogen and free ammonium content of all the samples remained constant throughout the storage periods. The high-fat samples showed a slight increase in free fatty acids, particularly in the samples stored at 76°.

"Storage of soybean meal apparently results in partial denaturation of the proteins as indicated by their decreased solubility in salt solution. A proteolysis is also indicated by the drop in true protein values. The nature of the marked decrease in digestibility in vitro is being studied."

34. Jones, D. Breese, and Gersdorff, Charles E. F. The effect of storage on the proteins of seeds and their flours. Soybeans and wheat. Proc. Am. Soc. Biol. Chemists. Vol. IX, No. 1, p. xlix. 1939.

"Marked changes occur in the proteins of seeds on storage or ageing, the extent varying with the kind of seed and conditions of storage. Although occurring much more rapidly in flours or meals, these changes also take place in the unground seeds.

"Defatted soybean meal stored for 1 year in bags at 24.4° decreased 18 percent in the amount of nitrogen extractable by 10 percent NaCl solution, 21 percent in digestibility, and nearly 12 percent in true protein value. Materially lower percentage changes occurred at - 1.1°.

"Denaturation of the proteins of wheat and of wheat flours occurred to a much larger extent and more rapidly than that of the soybean proteins. After 1 month's storage in sealed jars at 24.4°, the nitrogen extractable from white flour by 3 percent

NaCl had decreased 43 percent. At the end of 1 year, the percentage had dropped to approximately 50 percent. Large decreases in the amount of nitrogen extractable with 70 percent alcohol and Na salicylate also occurred, with similar changes occurring in whole wheat flour. Indications of extensive proteolysis in the wheat flours were shown by increased values in amino nitrogen and decreases in true protein values and in nitrogen precipitable by trichloracetic acid.

"Changes also occurred in the whole, unground wheat kernels. After storage in jars at 24.4° for 9 months, the percentages of nitrogen extractable by NaCl, alcohol, and sodium salicylate had decreased 26, 18, and 9 percent, respectively. Considerable proteolysis had also occurred."

35. Kansas Agricultural Experiment Station Tech. Bul. 1. Milling and baking quality of wheat and flour. pp. 141-142. 1916.

"When wheat undergoes the process of ageing, the gluten undergoes this desirable transformation. It becomes more elastic and pliable. The dough from flour made of such wheat is more easily handled, requires less fermentation and gives a loaf of larger volume and better texture.

....."It seems entirely possible that if wheat is treated with a certain amount of moisture and then subjected to heat for a short time this will have the same effect of natural ageing. The amount of moisture added should have a definite relation to the moisture content; the higher the moisture content the less the amount of water needed."

36. Kelly, C. F., Stahl, B. M., Salmon, S. C., and Black, R. H. Wheat storage in experimental farm-type bins. U. S. Dept. Agr. Cir. No. 637, 245 pp. 1942.

"Various measurements were used to determine the quality of the wheat during the storage period. The external evidences of wheat deterioration (such as percent total damage, test weight, odor, etc.) usually were not apparent until the condition of the grain had been lowered enough to affect its commercial grade. However, percent germination and fat acidity of sound wheat were found to be valuable indices of incipient deterioration that is not apparent from grade examination, and graphs are presented to show the relation of percent total damage and percent germination to fat acidity through the range from 10 to 40 units of fat acidity."....

37. Kozmin, Natalie P., Alakrenskaya, Katherin A., and Bondarev, Valerie D. "Ripening" of wheat flour and its biochemical basis. Muhlenlab. Vol. 4, pp, 16-32 (1934); C. A. Vol. 28, p. 6207[8]. 1934.

"Ripening of the gluten in stored flour causes an increase in elasticity; gluten of strong flours becomes even more elastic and short. The effect of storage varies according to the flour type. The real cause of ripening is the hydrolysis of the fat through the accumulation of considerable amounts (up to 1 percent) of free unsaturated acids--oleic, linoleic, linolenic. On removal of these acids by ether extraction aged flour is 'rejuvenated', i.e. the original character of the gluten is restored. Conversely the addition of these acids to fresh flour has a marked ageing effect. Storage temperature is very important: at 12°-15° the production of free acids practically ceases; at 45° the upper limit for the activity of fat-splitting enzymes is not yet attained. Fat hydrolysis occurs independently of the supply of oxygen; in the presence of oxygen rancidity develops."

38. Kozmin, Natalie P. The ageing of wheat flour and the nature of this process. Cer. Chem. Vol. 12, No. 2, pp. 165-171. March 1935.

"During the storage of flour at a high temperature there could be observed a strong rise of titratable acidity as well as an increase in the acid number of fat. The content of the free acids in the fat of this flour amounted to almost 50 percent.

"The removal of fat from the aged flour by ether extraction returned the gluten to its original quality, making it 'young' again."

Conclusions of the experiments are:

"During storage of flour a change in the quality of gluten in the direction of its strengthening has been observed. The direct cause of this change is the accumulation of free fatty acids in the flour, caused by a slow process of fat hydrolysis. The removal of fatty acids rejuvenates the flour, returning it to its original state.

"In turn the addition of free unsaturated fatty acids produces the same effect as natural ageing. Free unsaturated fatty acids (oleic, linoleic, linolenic, etc.) influence the colloid behavior of gluten in a specific manner, thickening the gel. Saturated fatty acids with the same amount of carbon atoms (stearinic, palmitinic, etc.) show no such effect." (Author probably means stearic and palmitic acids).

"The process of flour ageing proceeds without participation of oxygen, as fat hydrolysis does not require the presence of the same. Oxidation of flour pigments taking place during ageing has

no connection with the change of gluten quality."

"Temperature is the most important factor influencing ageing of the flour."

39. Kuhl, Hugo, and Kliefoth, D. Storage of wheat flour under different conditions. Muhlenlab. Vol. 4, pp. 65-70 (1934); C. A. Vol. 28, p. 6207[6]. 1934.

"Portions of the same flour, in one case unbleached and untreated, and in the other electrically bleached and treated with $KBrO_3$, were stored 6 months in tightly packed cloth sacks and in the form of cylinders compressed at 300 atmospheres. The effect of admixture of 3 percent wheat germ, both natural and defatted, on flours thus stored was also determined. The keeping quality of flour during storage is in every way enhanced by compression into a solid mass. The keeping quality of flour is influenced by its fat content, even small admixtures of germ leading to rapid deterioration. Admixture of defatted germ has little or no effect. Flour treated with $KBrO_3$ and electrically bleached does not keep so well as untreated, unbleached flour, and falls off somewhat in baking quality on storage."

40. Kuhl, Hugo. The effect of long storage on flour. Mehl. u. Brot. No. 23, pp. 1-5 (1935); Chem. Zentr. Vol. 1, p. 912 (1936); C. A. Vol. 31, p. 5385[1]. 1937.

"Storing the flour under a pressure of 300 atmospheres increased its keeping qualities. No moths developed during prolonged storage and no fungus mold proliferation and no musty odor were evident. Untreated flour was more stable to storage than that treated with bromate or electrolytically bleached. The fatty acids of the embryo at first have a favorable, but after a long storage an unfavorable effect. Wheat embryos freed from their fatty acids by compression methods decidedly improved the baking qualities of flour stored for a long period and overcame the undesirable effects of treatment with bromate and bleaching. Discoloration appearing after a very long storage is due to the action of the oxidases."

41. Ladd, E. F. Tempering of durum wheat; winter wheat versus spring wheat. N. Dak. Spec. Bul. Vol. 1, No. 36, pp. 414-415. 1911.

See reference number 46, this bibliography, for review.

42. Leavitt, Sherman, and Le Clerc, J. A. Change in the composition of unground cereals during storage. Jour. Ind. and Eng. Chem. Vol. 1, pp. 299-302. 1909.

The authors found notable decreases in the percentage of sugar in corn which was stored for 2 years; barley and oats showed small decreases while wheat and rye changed slightly. Some samples of wheat showed an actual increase in sugar content. The other constituents changed very little or not at all.

43. Le Clerc, J. A., Wessling, H. L., Bailey, L. H., and Gordon, W. O. Composition and baking value of different particles of flour. Operative Miller, Vol. 24, pp. 257-258. 1919.

"The object of this investigation was to determine the difference, if any, in the chemical composition and likewise in the baking quality of the various sized particles of which every flour is composed.....The following tentative conclusions may be drawn from the experiments, viz., that in most flours there are three almost distinct grades: (1) A coarse portion; (2) A very fine portion; (3) A medium fine portion. It was also found: That less than one-fourth of the flour belongs to the coarse, one-third to the finest and the remainder or approximately one-half to the intermediate; that the quality of the coarse and very fine portions or separates is inferior to that of the intermediate; that the very fine granulate is by far the poorest part of the flour, both as regards the quantity and quality of the gluten and as regards the quality of the bread produced from it; that those portions which remain on the Nos. 18,20 and 21 silks are very similar in gluten content and produce bread of equally high quality; that in every case the quality of the bread made from the intermediate granulates is superior to that of the original flour; that a superior bread flour could be made by selecting only those granulates which show superior value."

44. McCaig, J. D., and McCalla, A. G. Changes in the physical properties of gluten with ageing of flour. Can. Jour. of Res. Sec. C, Vol. 19, pp. 163-176. May 1941.

"The physical properties of gluten, as determined by the hydration of the gluten between pH 4 and 7, are deleteriously affected by ageing of flour. Similar effects are obtained by adding linolic acid, whereas some of the effects of ageing can be removed by extraction of the flour with ether. The original quality of the gluten is not restored by such extraction. Gluten from aged deteriorated flour swells enormously in 0.1N acetic acid; such hydration is not an indication of good quality but rather of resistance to dispersion. Some freshly milled flours produce gluten possessing the physical characteristics of gluten from aged deteriorated flour.

"It is concluded that the quality of gluten depends to a considerable extent on the nature of the absorbed lipoids. Many of the characteristics of gluten are determined by relatively insoluble (unidentified) lipoid substances, whereas the absence of such lipoids and the formation of fatty acids during ageing are deleterious to gluten quality."

45. McCalla, A. G., McCaig, J. D., and Paul, A. D. Effect of various conditions of storage on baking quality of flour. Can. Jour of Res. Sec. C, Vol. 17, pp. 452-459. 1939.

"Flour stored in sealers in a refrigerator at 2° C. did not change in quality for 22 months after milling. Similar flours stored in sealers at room temperature deteriorated significantly within three months, while a third lot stored in small bags at room temperature showed first a definite improvement and then rapid deterioration. At the end of 22 months flours stored in sacks were much the poorest. Acidity of all flours increased with storage, but this determination was of little value in estimating flour quality."

46. Mangels, C. E. Effect of storage on baking quality of common and durum wheats. Cer. Chem. Vol. 1, No. 4, pp. 169-178. July 1924.

"A general impression exists that both wheat and flour improve in storage, and this is probably true under certain conditions. A review of the literature indicates that studies on this point have been rather limited.

"C. E. Saunders (1) 1/ and Shutt (2), of the Ottawa station, studied the effect of storage on the baking quality of wheat and flour. Saunders found that both wheat and flour improved in water absorption and in shape of loaf when stored over long periods. The author also states 'In regard to loaf volume some irregularities occurred for which no satisfactory explanation can be offered at present.'

"Shutt made chemical studies on the wheat and flour samples used by Saunders and found that total protein and gliadin tend to increase in storage but the difference is hardly sufficient to be of significance. No durum wheats were used by Saunders and Shutt. Saunders in a later report (3) gives the following conclusions: 'The table and outline drawings show clearly that most of these varieties of wheat are improved very considerably in baking qualities by long storage, either as wheat or as flour. The highest

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1/ Figures in parentheses refer to "bibliography", p. 20

baking strength was attained when the wheat was stored about three or four years. When the material was stored as flour the changes were more rapid and the highest baking strength was reached in two or three years. It appears that by storing the material as flour a higher bakingstrength can be obtained than is possible when the material is stored as wheat. Ultimately deterioration sets in rather earlier with the flour than with the wheat, but it is evident that storage under good conditions is safe for at least ten years.' The author also states, 'In spite of all the precautions taken the results show a number of provoking irregularities,' and these irregularities are ascribed to variation in quality of yeast. The wheat and flour samples in this case were stored in an unheated room.

"Snyder (4) stored flour milled from spring and winter wheat in a dry, well-ventilated warehouse, four, eight, and twelve months, and compared the stored flour with fresh flour milled from similar wheat. Analyses and baking tests indicated that flour stored under these conditions shows no deterioration in quality, and a slight improvement was noted in size and color of loaf.

"Swanson, Willard, and Fitz (5) stored flour in steam heated and unheated rooms for comparatively long periods. They find loss of moisture, but otherwise no significant change in baking quality or composition.

"Stockham (6) reports improvement in baking quality of flour stored in a humid cabinet at 85-95° F. for three weeks as compared with original and with flour stored in a dessicator over sulphuric acid.

"Ladd (7) reports results of a storage test with durum patents and clears. These flours were stored for three months during hot summer weather (May 17 to August 17, 1911). Six out of seven samples show a loss in volume, but absorption was higher for all samples, and color of the clear flours showed marked improvement.

"H. L. White (8) found that flour stored for two years showed no considerable increase in acidity. The hard wheat flours maintained their baking qualities better than the durum flours, but both showed decrease in volume."....

Conclusion is that warm storage is more detrimental to flour quality than cool storage. After 11 months' storage, all lots of flour showed some deterioration, but the durum flours showed relatively greater deterioration than the common wheat flours.

Bibliography

"1. (a) Canadian Experimental Farms Report 1907, pp. 219-223.
(b) Canadian Experimental Farms Report 1909, pp. 204-208.
(c) Canadian Experimental Farms Report 1910, pp. 167-170.
2. Canadian Experimental Farms Report 1911, pp. 168-171.
3. Bulletin 97, pp. 28-38. Department of Agriculture, Dom. of Can. (1921).
4. Minnesota Agricultural Experiment Station Bulletin 85, pp. 213-217. (1904).
5. Kansas Agricultural Experiment Station, Bulletin 202, p. 133. (1915).
6. North Dakota Special Bulletin. Vol. 2, No. 7, p. 118. (1912).
7. North Dakota Special Bulletin. Vol. 1, No. 36, pp. 414-415. (1911).
8. North Dakota Report of Food Commissioner, pp. 140-143. (1911)."

47. Miège. The maturing of wheat and flour. Compt. rend. acad. agr. France. Vol. 19, pp. 636-9 (1933); C. A. Vol. 27, p. 4314[3]. 1933.

"The effects of various types of storage on wheat and flour have been determined. The methods of storage tested have been: in bags, in bulk, kept covered at a temperature of 21°, in the air, day and night and in hermetically sealed bottles. Storage in bulk in the air causes a general improvement of the quality of the wheat. This is due to a slow oxidation of the grain reserves which causes a diminution of the carbohydrates and a modification of the physical properties of the gluten. Under these conditions there is a lowering of the specific gravity and an increase in the moisture of the grain. Tenacity and baking value are greatly improved by storage."

48. National Association of British and Irish Millers Ltd. Correspondence between London representative of U. S. Department of Agriculture and the Association regarding transactions relating to "old" wheat. 1931-1932.

In 1931, the fact that United States wheat offered for sale by the Farm Board was one or two years old was one of the reasons advanced by the National Association of British and Irish Millers for refusing to accept future deliveries of United States wheat on a grade basis with grade certificate being prima facie evidence that delivery was of condition and quality contracted for.

49. Northwestern Miller. Wheat gets sick. Northwestern Miller. Vol. 209, No. 2, p. 18a. January 14, 1942.

"In a recent issue of The Piedmont Bulletin, official publication of the Piedmont Millers Association, some comments on 'sick wheat' by Charles Molin, supervisor of the Virginia Division of Markets, are presented."....

"Mr. Molin points out that moisture has been an important factor in the grading of the 1941 wheat crop in Virginia and expresses the opinion that some wheat went into storage in mill and farm granaries with moisture contents higher than normal. The warm weather of the summer extended well into the fall, and much of the autumn went by without the occurrence of any considerable cold weather. Such conditions are regarded as furnishing excellent opportunity for the development of 'sick wheat', and the writer emphasizes the dangers attending the storage of grain with a moisture content of 14 percent or above.

"Attention is called to the necessity of dissipating the heat stored in the grain as a result of summer temperatures. It is recommended that wheat should be cooled to 60° F., or lower, as quickly as possible, by 'turning' it and passing it over separators, or by some other means which subjects it to thorough aeration.

"It is pointed out that at temperatures above 60° there is likely to be insect infestation, and that with the rise in temperature accompanying infestation, the development of sick wheat will progress rapidly.

"In describing 'sick wheat', Mr. Molin brought out that 'bin burnt' indicates a late stage of 'sickness'. It is stated that bin burnt wheat is unsuitable for milling if the production of good flour is the objective. Continuing the description, Mr. Molin said, 'The ash and acidity of the flour /from bin burnt wheat/ is increased and the quality markedly decreased. However, the good flour-making properties of wheat have been adversely affected by the development of sick wheat long before the bin burnt stage is reached.'

"The germ of a healthy kernel is then described as a fatty substance, the extraction of which from the floury parts of the grain is dependent upon the flattening of the germ into disc-shaped bodies. These bodies may be separated from the floury products. 'In sick wheat', the writer continues, 'the germ tends to pulverize rather than flatten, and separation is difficult if not impossible. The germ becomes slightly depressed, and the coating, of a grayish-brown appearance, rather difficult to detect unless one is on the lookout with an experienced eye.'

"'If the germ coating is delicately peeled off, the dark-brown to black powdery appearance of the germ underneath, which has little resemblance to a healthy germ, may be seen. The general appearance of such wheat to a casual observer is good, but its milling qualities are disappointing.'"

50. Nature. Storage of National Wheatmeal. Nature, Vol. 149, No. 3788. June 6, 1942.

"A report on the problem of the storage qualities of National Wheatmeal has been published by the Research Association of British Flour-Millers in Milling of May 23. Storage trials were carried out over a period of a year and included not only laboratory experiments but also tests under commercial conditions in mills, bakeries and buffer depots. Moisture content is the most important factor determining storage life: thus at 14, 14-1/2 and 15-1/2 percent moisture contents, provided the storage conditions are good and a sound wheat grist is used, the wheatmeals will keep in good condition for 9 months, 4-6 months and 2 months, respectively. Temperature is a further factor, and whereas at 60° F. a wheatmeal of 15-1/2 percent moisture remained in good condition for 11 weeks, at 77° F. it kept only for 3-4 weeks. An additional point of importance revealed by the experiments is that National Wheatmeal is more prone to insect infestation than white flour."

51. Oklahoma Agricultural and Mechanical College. Agronomists experiment with fumigants for farms. Northwestern Miller. Vol. 211, No. 8, p. 16. August 19, 1942.

Agronomists from the Oklahoma Agricultural and Mechanical College have experimented with carbon disulphide as a fumigant. Because of its extremely high inflammable and explosive properties it is used for fumigation principally in a mixture with other fumigants or alone on a farm for treatment of grain in isolated bins. Workers found that the agent has no significant effect upon the germination or baking quality of wheat unless concentrations exceeding four times the recommended rate of approximately 4 gallons per 1,000 bushels are used. The agronomists state further that treatments heavy enough to affect germination also reduced loaf volume and changed the characteristics of the dough.

52. Parker, John H. Wheat quality as affected by farm storage. Northwestern Miller. Vol. 177, No. 2, p. 118. January 10, 1934.

"Storage damage in wheat is a serious problem at least one year in five on the average, even in a relatively dry wheat growing area such as central Kansas.

"In general it may be said that wheat with 13 percent or less moisture will not be damaged by heating in storage, while

that with 14 percent or more moisture is likely to be damaged. This line is not a sharp one, and will vary with temperature and humidity of the air and other factors."

53. Phillips, C. Louise. Heating and spoiling of grain. Part I. Abstracts and references. U. S. Dept. Agr. Bur. Markets and Crop. Est. Mimeo. pp. 1-22. 1921.

54. Phillips, C. Louise. Heating and spoiling of grain. Part II. Abstracts and references. U. S. Dept. Agr. Bur. Markets and Crop Est. Mimeo. pp. 23-41. 1921.

55. Phillips, C. Louise. Respiration of grain, and its relation to the heating of grain. Sweat in wheat and flour. Abstracts and references. U. S. Dept. Agr. Bur. Ag. Econ. Mimeo. 7 pp. 1922.

56. Phillips, O. F. See reference number 22, this bibliography.

57. Pièttre, Maurice. Maturation of grains of wheat; influence of certain physicochemical phenomena. Compt. rend. Vol. 198, pp. 608-611. 1934. C. A. Vol. 28, p. 2421[6]. 1934.

The maturation of green wheat grains stored at -5° to -7° is characterized by a rapid decrease within 4 days, of reducing and nonreducing sugars, and within 8 days, of globulin and albumin, coincident with a rapid decrease in water.

58. Ramstad, Paul E., and Geddes, W. F. The respiration and storage behavior of soybeans. Minn. Agr. Exp. Sta. Tech. Bul. 156. 1942.

"The lowest moisture content at which soybeans were observed to heat was 15.6 percent. Increases in respiration with time of storage were marked in soybeans containing over 13 percent moisture when stored at room temperature; furthermore, the iodine number of oil from such beans was greatly reduced, although the quantity of oil did not seem to be diminished. Soybeans remained sound and retained their viability well at a moisture content of 15.8 percent for a year and a half when stored at 4° C. On the other hand, when stored at room temperature, viability was seriously diminished even below a moisture content of 10 percent."

"Rapid loss of viability was caused by conditions which favored the growth of microorganisms in soybeans. Viability was better retained in beans stored at 15 percent moisture and a temperature of 4° C. than in beans from the same lot stored at 9 percent moisture and room temperature. To retain high maximum germination capacity, soybeans should be stored at a low moisture content (approximately 10 percent) and at as low a temperature as feasible."

59. Robertson, D. W., Fifield, C. C., and Zeleny, Lawrence. Milling, baking, and chemical properties of Colorado-grown Marquis and Kanred wheat stored 9 to 17 years. Jour. Am. Soc. Agron. Vol. 31, pp. 851-856. 1939.

"Milling and baking tests were made with eight samples of Marquis wheat and three samples of Kanred wheat stored at Fort Collins, Colorado, in a dry, unheated room for periods up to 17 years. There was a definite and fairly regular increase in fat acidity with storage, indicating a certain amount of progressive deterioration on storage. Satisfactory flour yields were obtained in all cases and unusual tempering was not required in any case. All lots made satisfactory bread, there being no indications of deterioration in baking quality in any of the samples.....There was no apparent relation between deterioration in viability as shown by germination tests and baking quality."

60. Robertson, D. W., and Lute, Anna M. Germination of seed of farm crops in Colorado after storage for various periods of years. Jour. Am. Soc. Agron. Vol. 29, pp. 822-834. 1937.

"Germination tests were made on the seeds of various farm crops adapted to Colorado conditions which had been stored in a dry, unheated room for periods varying from 1 to 15 years.

"The germination percentage of wheat, oats, and barley declined slowly for the first 10-year period with a sharp break in germination between the 10th and 12th years. The drop in germination was as great or greater from the tenth to the fifteenth year as it was from the first to the tenth year."

61. Robertson, D. W., Lute, A. M., and Gardner, Robt. Effect of relative humidity on viability, moisture content, and respiration of wheat, oats, and barley seed in storage. Jour. Ag. Res. Vol. 59, pp. 281-291. 1939.

"The data showing the rates of change of moisture and viability with humidity offer a means of predicting the maximum time which would be safe for storage under any given relative humidity, assuming temperature conditions comparable to those of the experiment."

62. Rusca, Ralph A., and Gerdes, Francis L. Effects of artificially drying seed cotton on certain quality elements of cottonseed in storage. U. S. Dept. Agr. Cir. No. 651, p. 16. July 1942.

"The conditions under which cottonseed is stored have an important bearing on the quality of the seed after prolonged periods of storage. Excessive moisture content and overheating of the

seed not only have an ultimate adverse effect on the quality of oil extracted from stored seed but they may also influence its germinative properties."....

"Results of the 2-year study, in which 23 cottons were used, have been compiled and analyzed. They indicate that with green, damp, or wet seed cottons, the process of artificially drying before ginning did not cause an increase in the rate of deterioration of the seed in storage; that in fact, it caused retardation of the formation of free fatty acids. The higher the drying temperature used, the less was the free fatty acid content of the seed at the end of the 90-day storage period."....

"Germination tests on the undried and dried seed indicate that a free fatty acid content of 2 percent becomes critical as far as cottonseed germination is concerned."

63. Saunders, C. E. Canadian Experimental Farms Report 1907, pp. 219-223. See reference number 46, this bibliography, for review.

64. Saunders, C. E. Canadian Experimental Farms Report 1909, pp. 204-208. See reference number 46, this bibliography, for review.

65. Saunders, C. E. Canadian Experimental Farms Report 1910, pp. 167-170. See reference number 46, this bibliography, for review.

66. Saunders, C. E. Dept. of Agr. Dom. of Can. Bul. 97, pp. 28-38. 1921. See reference number 46, this bibliography, for review.

67. Sayre, J. D. Storage tests with seed corn. Ohio Jour. Sci. Vol.40, pp. 181-5 (1940); Exp. Sta. Rec. Vol. 85, p. 341. 1941.

"Kernels of Clarage corn, sealed in glass tubes and containing 18 percent moisture, remained viable after 6 years when stored at temperatures below freezing but died in less than 6 months at room temperature (about 30° C.) When stored at about 30° C. kernels stored in oxygen died in 3 years and in nitrogen or carbon dioxide decreased noticeably in germination, whereas those stored at low temperatures in these gases or air gave good germination after 5 years."

68. Sharp, Paul Francis. Wheat and Flour Studies II. Ageing I. The change in hydrogen-ion concentration of wheat and mill products with age. Cer. Chem. Vol. 1, No. 3, pp. 117-132. 1924.

"The hydrogen-ion concentration of ground wheat increases more rapidly than that of unground wheat."

69. Shellenberger, J. A. Variation in the baking quality of wheat during storage. Cer. Chem. Vol. 16, No. 5, pp. 676-682. September 1939.

"The baking quality of wheat is improved by storage after harvest, but the betterment observed during this investigation was not particularly impressive. This conclusion is based on the study of four classes of wheat, obtained from eight states, during the 1938 harvest.

"The experimental baking test, applied to new wheat, provides a reliable indication of the potential baking quality of the crop.

"There appears to be a direct relationship between the viability of wheat and its baking quality."

70. Shollenberger, J. H., and Marshall, W. K. The effect of storage on the baking strength of wheat and flour. Unpublished report of milling investigations. U. S. Dept. of Agr. Bur. Agr. Econ. 1925.

"The baking results on flours stored in tin cans do not indicate that the length of storage had any appreciable effect upon the baking strength of the flour. The chemical data on these flour samples showed a gradual loss in moisture and a tendency to increase in acidity and water-soluble nitrogen. The proportion of gliadin to gluten increased while the wet and dry gluten decreased during the latter part of storage. This decrease in gluten may have been due to some enzymic action which decreased its cohesiveness thereby preventing its full recovery in washing."

The flours stored in cotton bags showed marked changes in baking strength and chemical composition in the latter stages of storage.

The authors state, however, that, "The results of these storage tests, it is believed, do not point to any very definite conclusions. In order to obtain more definite conclusions, it would be necessary to conduct experiments in which the moisture content of the wheat can be controlled during storage and in a room secure from weevil infestations."

71. Shutt, F. T. Influence of age on wheat and flour. Canadian Experimental Farms Report 1911, pp. 168-171.

See reference number 46, this bibliography, for review.

72. Simpson, D. M. Relation of moisture content and method of storage to deterioration of stored cottonseed. Jour. Agr. Res. Vol. 50, pp. 449-456. 1935.

"Storage experiments with sea-island and upland cottonseed under the humid conditions prevailing at James Island, South Carolina, showed that in ordinary storage cottonseed deteriorates rapidly after two years. A definite relation is indicated between the moisture condition of the seed during storage and the rapidity of deterioration. Sea-island seeds, with a moisture content reduced below 8 percent, when stored in tin containers to prevent the rapid reabsorption of moisture, retained their germination percentage with only slight improvement for 4-1/2 years. Upland cottonseed stored under various conditions and containing from 8.75 to 13.78 percent moisture deteriorated rapidly when the moisture in the stored seed remained above 10 percent. Dried seed stored to prevent reabsorption of moisture showed only slight deterioration after 2-1/2 years. Seeds containing 13.78 percent moisture and stored to prevent drying were all dead nine months after the beginning of storage."

73. Sinclair, A. T., and McCalla, A. G. The influence of lipoids on the quality and keeping properties of flour. Can. Jour. Res. Sec. C, Vol. 15, pp. 187-203. May 1937.

"The keeping properties of different flours varied considerably. Ageing was accompanied by increased absorption regardless of whether the flour deteriorated in baking quality. Increased acidity developed in all flours, but was not a good measure of deterioration. Storage in sealed containers favored acidity increases, while storage in sacks favored deterioration. A decrease in ether extract accompanied deterioration, while decrease in the less soluble lipoids appeared to take place in all samples.

"The changes in physical properties of gluten gave the best indication of deterioration. Gluten from deteriorated flour was harsh, spongy and short, and could not be completely dispersed in sodium salicylate. Unsaturated fatty acids added to flour had the same effects on gluten, but not on baking quality. Ground wheat germ added to deteriorated flour improved the gluten and restored its solubility. The more insoluble germ lipoids were the effective substances. Alcohol extraction of flour caused deterioration, but gluten quality was largely restored by addition of germ. All results indicate the lipoids are absorbed on the protein of the gluten.

"It is concluded that the unique physical properties of gluten are to a considerable extent dependent on the relatively insoluble lipoids present. The possibility of gluten denaturation being a breakdown of the protein-lipoid complex is discussed."

74. Smith, W. D. and others. Artificial drying of rice on the farm. U. S. Dept. Agr. Cir. No. 292. 1933.

"A drying air temperature of 120° F. can be used without injury to the rice if the moisture content is reduced only about 2 percent at each drying operation and the rice is allowed to remain in storage from 12 to 14 hours between dryings."

75. Snyder, Harry. Wheat and flour investigations. Minn. Agr. Exp. Sta. Bul. 85, pp. 213-217. 1904.

See reference number 46, this bibliography, for review.

76. Stockham, W. L. Improvement of flour in storage. N. Dak. Spec. Bul. Vol. 2, No. 7, p. 118. 1912.

See reference number 46, this bibliography, for review.

77. Swanson, A. F. Long time storage of winter wheat. Jour. Am. Soc. Agron. Vol. 31, No. 10, pp. 896-97. October 1939.

Milling and baking investigations on 11-year old wheat apparently stored when thoroughly dry and of low moisture content, free from weevils, and relatively free from cracked grain indicated that the wheat milled satisfactorily, that it baked a good loaf of bread, and that the flour gave a dough with a long mixing time and excellent milling tolerance. The milling and baking results compared favorably with those of the adapted varieties grown in the same region in 1938.

78. Swanson, C. O. The milling and baking qualities of a dead wheat. Northwestern Miller. Vol. 146, p. 154. April 14, 1926.

In referring to wheat which had been stored under favorable conditions for 25 years, the author states:

"These dead kernels may appear plump and sound, and according to the milling tests on this dead wheat they may yield a normal amount of flour. Such dead kernels, however, may increase the percent of ash in the flour and the flour has little value in baking beyond being a filler."

79. Swanson, C. O. Wheat and flour quality. Burgess Publishing Co. 227 pp. 1938.

"A seed may die and yet the enzyme activity, although reduced, will persist for a considerable time after the life principle leaves, like the tools of a mechanic which remain after he is gone. The diastatic activity of a sample of wheat 42 years old, which had been dead a long time, since wheat usually dies in less than 10 years,

was found to be 122 milligrams maltose per 10 grams of wheat. Many samples of live wheat often give less maltose than this." (p.88)

"As a rule flour is stored for much shorter period than wheat and from what is known it is evident that flour does deteriorate much more rapidly than wheat. It has already been noted that when the wheat kernel is crushed the enzymes have a greater opportunity to act on the substrate. The fat in flour is also more exposed to effects of oxidation. Long storage of flour has shown an increase in hydrogen-ion concentration. It is generally considered that flour improves some in baking value after the first few weeks of storage. Some of these improvements are probably related to the changes which take place in the lipoids. (p. 126)

80. Swanson, C. O. Some factors involved in damage to wheat quality. Cer. Chem. Vol. 11, No. 2, pp. 173-199. March 1934.

"One of the best measures for the extent of damage which has taken place in wheat is the determination of the amount of acidity which has developed in the wheat fat. This is designated as rancidity. The development of this condition is, however, related to the air supply. In the entire exclusion of air this will not develop. Hence the conditions which favor the development of mold and rancidity are closely related. However, since damage to quality also took place in the sealed bottles, absence of high rancidity is not proof of lack of damage.

"Sugar was not increased until the moisture was above 18 percent. The diastatic activity was not increased by high moisture; on the contrary, the diastatic activity was greatest in the samples stored with low moisture. Thus it is not possible to increase either the sugar content or the diastatic activity by adding water in amounts which are safe for storage or in amounts used in tempering wheat."

81. Swanson, C. O. The ever-changing wheat--and the principles of its handling. Northwestern Miller. Vol. 195, p. 21. September 14, 1938.

"While the exact relationship between loss in viability, or germinating power, and quality have not been as extensively demonstrated as would be desirable, the following statements may be made. If wheat has a high percent of viability, it has not suffered any damage due to storage conditions. If the viability is low, it has suffered some damage, somewhat in proportion to the loss in viability. If a wheat is dead, the damage may be considerable. The deterioration in quality, however, does not stop when the wheat dies. Hence, how seriously it is damaged depends on how long it has been dead. Then it depends on the quality of the wheat at the beginning of storage."

82. Swanson, C. O. The effect of low temperature in preventing damage to wheat stored with high moisture content. Cer. Chem. Vol. 18, No. 3, pp. 299-315. May 1941.

"There was no decrease in viability in the samples stored in the cold (41° F.), while all those stored at higher moistures in the laboratory were dead. Wheat of good viability shows no damage to its milling and baking qualities.....Wheat may be stored at 41° F. at high moisture for many months without suffering any damage to its milling and baking qualities. When wheat has good viability it has suffered no damage to the gluten structure even when a slight odor indicating unsoundness could be detected."

83. Swanson, C. O. Effects of moisture on the physical and other properties of wheat. Cer. Chem. Vol. 18, No. 6, pp. 705-729. November 1941.

Results from exposing wheat before threshing to various amounts of moisture and also from wetting threshed wheat grain to various moisture percentages from one to six times show that the greatest apparent effects were a lowering of test weight and a decrease in vitreous condition. The hardness as determined by the barley pearler was also decreased. Since these properties are important grain grading factors, wetting wheat either artificially or by exposure to rain or by adding water to the grain and then drying did seriously affect the grading values of the grain.

"The decreases in test weight were not reflected in correspondingly lower flour yields in the samples wetted after threshing. The samples wetted as grain, the test weights of which had been reduced as much as 6 pounds, gave essentially as high flour yields as the samples not wetted or those wetted comparatively little. This was not due to closer milling, since the ash figures varied only within the experimental limits.....Because there was no loss of material, there should have been no decrease in flour yield simply because the space occupied by the kernels in the test kettle had been increased.

"The baking values obtained on representative samples did not correlate with the commercial grade of the grain nor with the severity of the treatment.....The curves made on the recording dough mixer showed a longer time of development and a decrease in height as a result of the more severe treatments."

84. Swanson, C. O., and Fenton, F. C. The quality of wheat as affected by farm storage. Kansas Agr. Exp. Sta. Tech. Bul. 33. 1932.

Tables are given showing the effect of damage resulting from storage on the chemical composition of wheat.

85. Swanson, C. O., Willard, J. T., and Fitz, L. A. Kansas flours: Chemical, baking, and storage tests. Kansas Agr. Exp. Sta. Bul. No. 202, p. 133. 1915.

See reference number 46, of this bibliography, for review.

86. Thomas, R. C. The role of certain fungi in the "sick wheat" problem. Ohio Bimonthly Bul. Vol. 22, No. 185, pp. 43-45. 1937.

"It is evident from this study that there is a great difference in the toxic effect of the byproducts of growth of various fungi, including molds, upon the viability of wheat. All of the organisms used have been found to be commonly associated with grains both in the field and in storage. This association becomes significant only when the moisture content of the grain is high and the temperature favorable for mold growth. Two strains of Aspergilli have been found to elaborate toxic products when grown upon bran. The toxicity of these products was demonstrated by the reduction of viability of normal wheat. What further changes these molds may cause in bringing about the condition known as 'sick wheat', rendering the grain inferior and milled products below standard, remain to be seen."

87. U. S. Dept. Agr. Clip Sheet No. 1253. Store soybeans dry. Release July 5, 1942.

"Soybean seed stored in bulk sometimes loses viability--the ability to sprout--to a serious extent. Tests by the U. S. D. A. in different regions indicate that this is mainly a matter of controlling the storage temperature and seed moisture. One lot of soybean seeds with 8 or 9 percent moisture, held at 35° F. for 8 years suffered no loss in viability, whereas another batch, with 13 or 14 percent moisture, held at 70° F., showed no germination after 20 months."

88. Wallaces' Farmer and Iowa Homestead. Don't give steers old feed. p. 3. April 18, 1942.

"Feeding beef steers exclusively on hay and corn that are several years old is now regarded as an unwise practice. Such feeds may have depreciated so much in vitamin content that the animals will develop edema, or swelling of the legs and quarters. Such affected animals may be condemned when shipped to market, and often some will die in the feed-lot."....

The Illinois Experiment Station also reports that beef cattle fed on three and four-year-old corn thrive well for some time, until their front legs begin to swell. Lameness, loss of appetite and rapid loss of flesh are other symptoms.

Chemical analysis of old yellow corn by Illinois Experiment Station workers has shown Vitamin A content only half as great as in new corn.

89. White, H. L. N. Dak. Report of Food Commissioner, pp. 140-143. 1911.

See reference number 46, this bibliography, for review.

90. Zeleny, Lawrence, and Coleman, D. A. Acidity in cereals and cereal products, its determination and significance. Cer. Chem. Vol. 15, pp. 580-595. 1938.

"The Bureau of Agricultural Economics, in an effort to improve existing methods for evaluating quality of the cereal grains, has been making a study of acidity as a possible practical indication of deteriorative changes occurring in the grain."....

"The acidic substances present in cereals and cereal products may be divided into three principal classes: (1) free fatty acids (2) acid phosphates and (3) amino acids. These acids are present in small quantities in all normal grain and under certain conditions increase in amount chiefly by virtue of the enzymatic hydrolysis of fats, phytin, and proteins, respectively."....

"A study of the individual acidity fractions in 246 samples of corn and of the same fractions in wheat undergoing deterioration in storage reveals the fact that only the fat acidity increases significantly during the early stages of spoilage."....

"Fat acidity alone appears to be a more reliable index of soundness in grain than either of the other types of acid present, or than any combination of these acid fractions as determined by any of the commonly used methods."

91. Zeleny, Lawrence. Fat acidity in relation to heating of corn in storage. Cer. Chem. Vol. 17, pp. 29-37. 1940. C. A. Vol. 34, p. 2090. 1940. *

"The rate at which heat is developed depends upon the moisture content of the grain, the temperature, the available O_2 supply, and upon certain characteristics of the grain itself, which are not completely understood. The acidity of grain, particularly of corn, is a more reliable measure of its degree of soundness than other available chemical or physical tests. Fat acidity is expressed in terms of mg. of KOH required to neutralize the free fatty acids extracted from 100 g. of corn calculated to a dry matter basis. The rate of spontaneous heating of grain can be predicted much more

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* C. A. abstract checked with Cer. Chem. publication.

accurately when moisture and fat acidity are considered together than with moisture alone. It was shown that corn with a moisture content of 17 percent and a fat acidity of 100 can be expected to heat in storage as rapidly as corn with a moisture content of 21 percent and a fat acidity value of 20."

92. Zeleny, Lawrence. Milling deteriorated wheat. Am. Miller Vol. 69, No. 11, pp. 34-37. November 1941.

Deterioration is measured by amount of free fatty acids.

"The Agricultural Marketing Administration is developing another type of test that may prove to be of value as an index of wheat and flour deteriorations. This test is designed to measure gluten protein in either wheat or flour by a method that utilizes the photoelectric cell or so-called 'electric eye.' The method is considerably simpler than the conventional Kjeldahl test and has the distinct advantage of being a measure of gluten protein rather than total protein content. Deterioration of wheat or flour in storage is frequently accompanied by a degradation of the gluten. This test is still in the developmental stage."

INDEX

Item	
Acid	
Amino	90
Fatty	4,37,44,62,73,90,92
Linoleic	37
Linolenic	37
Linolic	44
Number	38
Oleic	4,37
Phosphate	90
Acidity	
Corn	6
Cottonseed	62
Flour	16,17,26,30,38,45 46,59,70,73
Grain	90,91
Wheat	36,49,80
Aging	20,35,59,77
Amino	
Acid	90
Nitrogen	32
Ash	49,78
Aspergilli	86
Bacteria	4
Baking quality (See Quality)	
Barley	27,42,60
Bin burned	22,49
Bleaching	6,39
Buffer value	17
Carbohydrates	24,26,47
Soluble	7
Carbon	
Dioxide	18,19,28,67
Disulfide	51
Carboxyl group	4
Certificate final	48
Composition	
Change during aging	8,10 15,42,43,84
Compression	
Effect of	39,40
Container	
Effect of	8,15,27,32 39,45,47,73
Corn	5,14,18,31 42,90
Cottonseed	62,72
Damage	
Heat	10,21,22,52
Dead kernels	78,81
Deterioration	14,92
Dextrin	27
Diastatic activity	80
Digestibility	
Flour	32
Drying	12,62,74,83
Edema	88
Ethylene gas	3,20,28,29
Enzyme	
Enzymic action	7,21,24,26 32,79,90
Farm Board	48
Fat hydrolysis	38
Fats	26
Fatty acid (see Acid)	
Feeding	13,88
Fermentation	18
Flax	19
Flour	
Flour	7,8,16,17,24,25 26,34,38,39,40,43 44,45,70,79
Grade	17,37
Heat treatment	17
Quality (see Quality)	
Fumigants	2,3,20
Fungus	28,29,51
Growth	4,40,86

Item	
Germ	40,73
Defatted	39
Extraction	49
Natural	39
Germination (see Viability)	
Gliadin	46
Gluten	4,17,24,35,37,38,43 44,47,57,70,73,82,89
Grade	
Flour (see Flour)	
Hay	88
Heat	35
Heat damage (see Damage)	
Heat treatment	17
Heating	20,53,54,55,62,91
Hermetically sealed (see Containers)	
Humidity	16,52,61
Hydrogen-ion	
Concentration	4,17,25 30,44,68,79
Insect	
Infestation	49,50
Linoleic (see Acid)	
Linolenic (see Acid)	
Linolic (see Acid)	
Lipoids	44,73
Maltose	27
Maturity	28,57,69
Milling quality (see Quality)	
Moisture	11,16,17,19,23,35 49,50,52,61,62,67,70 72,77,80,83,86,87,91
Cause of deterioration	9,15
In aging	4
Drying	6
Wetting	6,83
Mustiness	21
Nitrogen	67
Soluble	17
Nutritive value	13,31
Oats	27,42,60
Oil	4,19,58,62
Oxygen	67,80,91
Supply, effect on storage	37
Particle size	43
Potassium bromate	39,40
Phosphorus	24
Phytin	90
Protein	24,25,26,31,32 33,34,46,90
Proteolytic action	7
Quality	
Baking	1,7,8,17,26,28,43 45,46,47,59,69 73,77,81,82,83
Flour	1
Fumigant, effect on	2,3,29
Grain	15,48
Milling	59,82,83
Rancidity	80
Respiration	9,11,19,28,55
Rice	74
Ripening	26,37
Rye	18,19,27,42
Saccharification	20
Sick wheat	21,22,23,86
Soil	1
Soybeans	33,34,58,87
Soybean meal	33,34
Specific gravity	47
Starch	22,27
Sugar	26,42,57,80
Temperature	5,12,15,16,32,38,45 46,49,50,52,58,61,62 67,69,74,82,86,87,91
Tempering	41
Viability	5,15,28,36,51 59,60,61,62,67 72,81,82,86,87
Vitamin	13
Vitamin A	88
Vitreousness	83

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